

Soft Particle Production in Cosmic Ray Showers

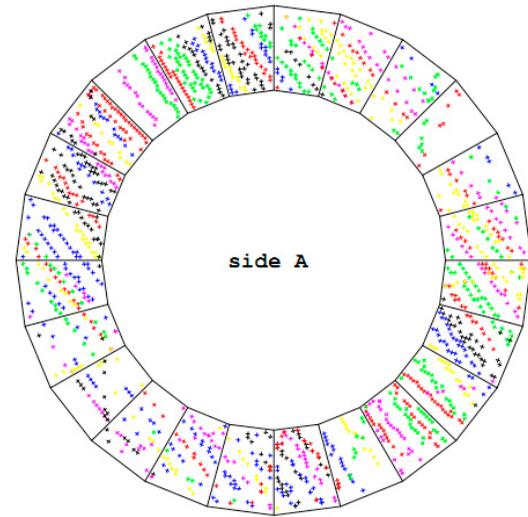
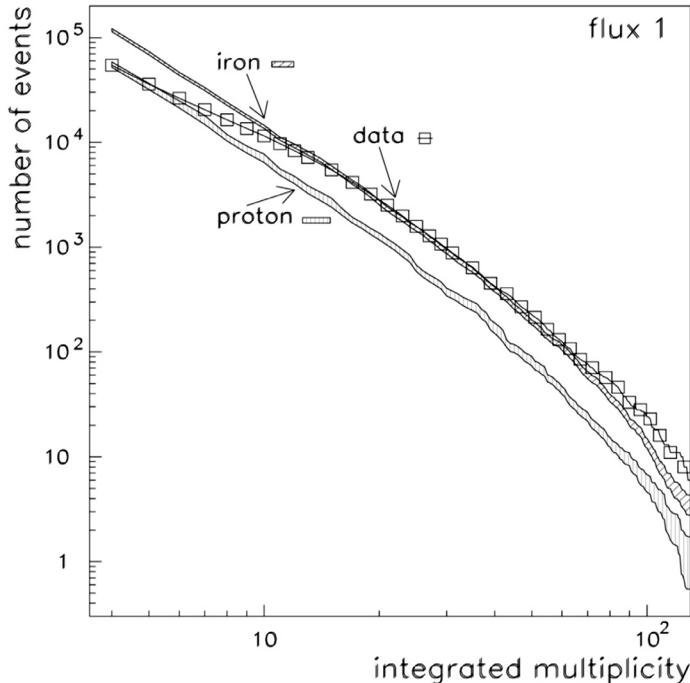


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DELPHI as a cosmic ray detector

- rock overburden: vertical cutoff ~ 52 GeV
- cosmic measurement in concurrence with normal run: effective uptime ~ 18 days



Bundles of parallel tracks in HCAL

- not every muon reconstructed (shadowing, saturation, non-active areas)
- high-multiplicity events mainly from EAS between 10^{15} – $10^{17.5}$ eV

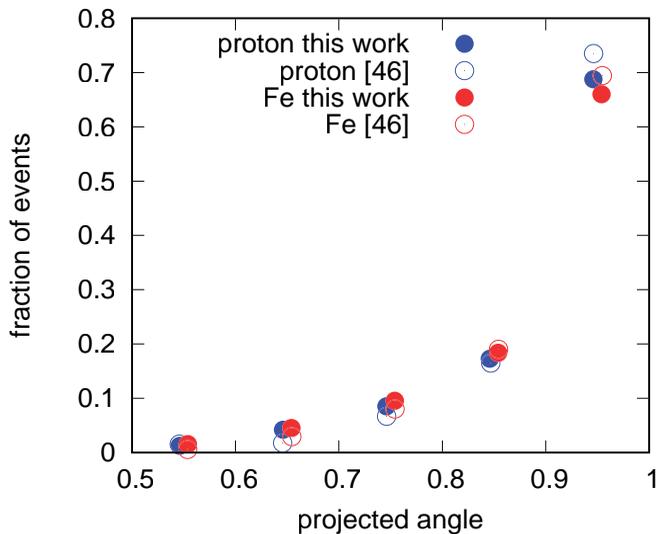
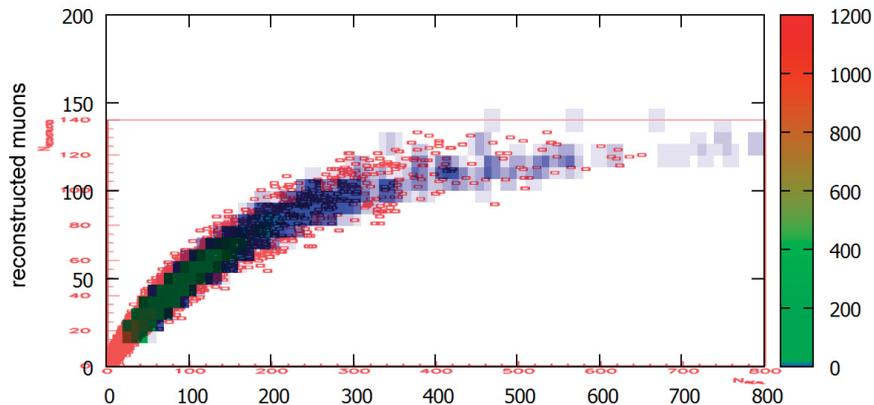
$$DPH_{20} = 2.24 \pm 0.17$$

$$DPH_{80} = 1.45 \pm 0.23$$

DELPHI Collaboration, *Astropart.Phys.*28:273-286,2007

DELPHI simulations

- whole relevant energy range (10^{14} – 10^{18} eV), spectrum and chemical composition from KASCADE + Grande
- simple “toy DELPHI” to roughly reproduce the response of the system to EAS
- fit of efficiency and saturation

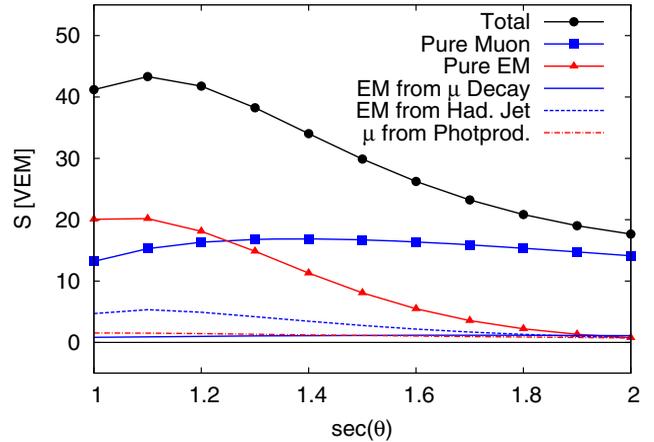
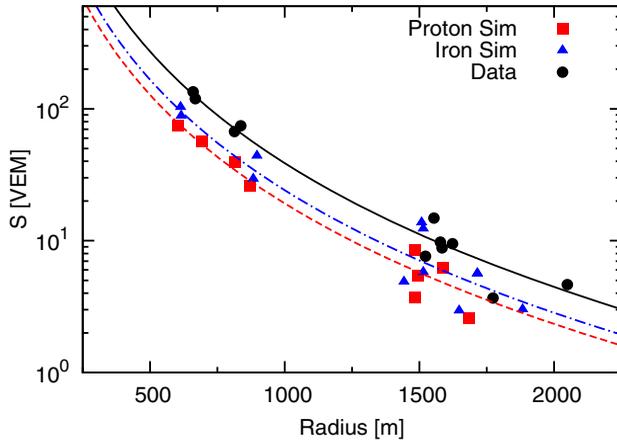
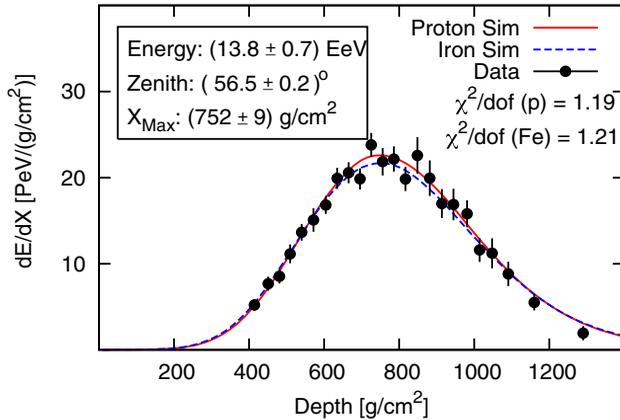


model	DPH_{20}	DPH_{80}	DPH_{20}	DPH_{80}
composition	p only	Fe only	mixed	mixed
QGSJET01	1.00	1.00	1.43	0.70
QGSJET-II-03	1.11	0.75	1.54	0.57
QGSJET-II-04	1.11	1.37	1.72	0.83
EPOS-LHC	0.85	0.86	1.27	0.59

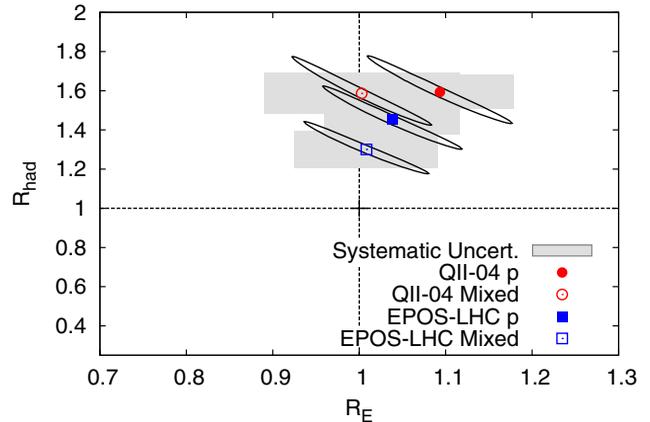
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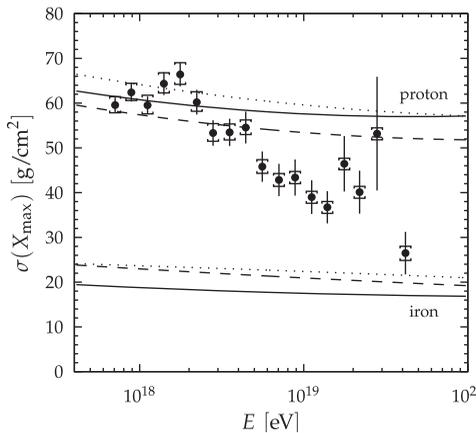
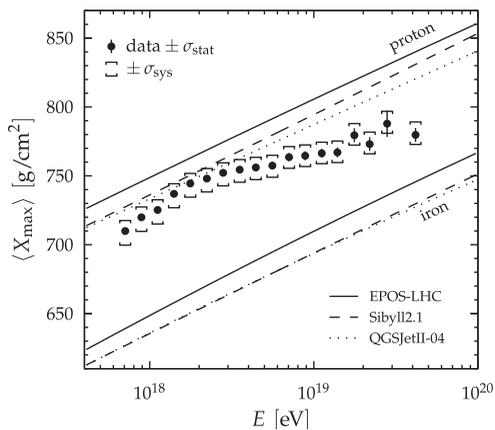
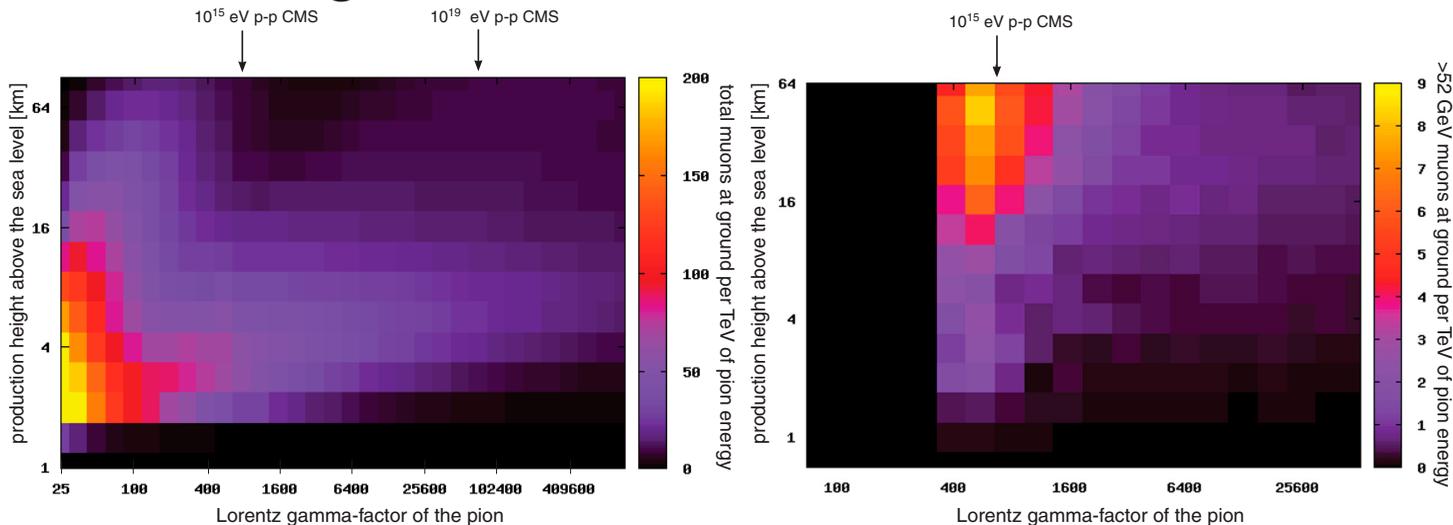
Auger muon excess



$$S_{\text{resc}}(R_E, R_{\text{had}})_{i,j} \equiv R_E S_{\text{EM},i,j} + R_{\text{had}} R_E^\alpha S_{\text{had},i,j}.$$



DELPHI-Auger connection?



- Auger depth of maximum constrains models
- Simulations at 3.2×10^{18} eV

Soft-particle addition model

particles: π , K, p , n

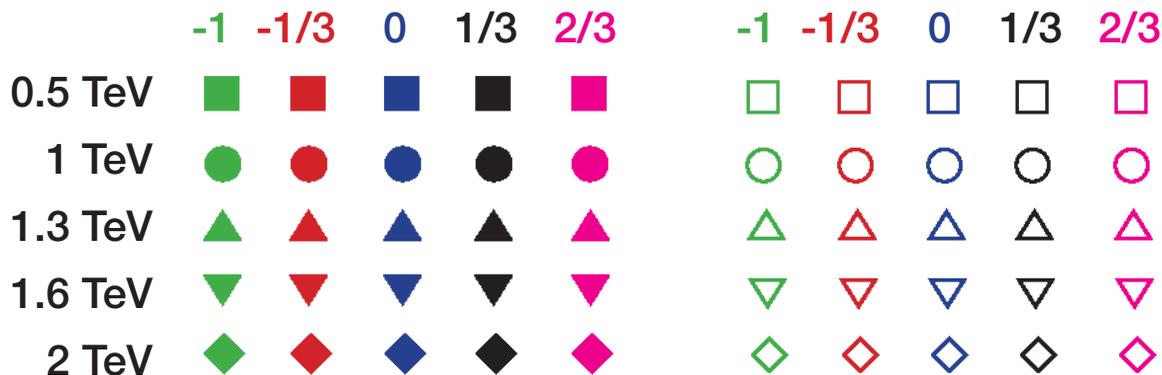
colour: (NWT+NWP) $^\eta$

distribution $p \exp(-p/p_0)$

angle: within $\pm 0.1^\circ$ from axis in c.m.s.

shape: energy treshold (or special p_0)

filled vs. empty: p_0



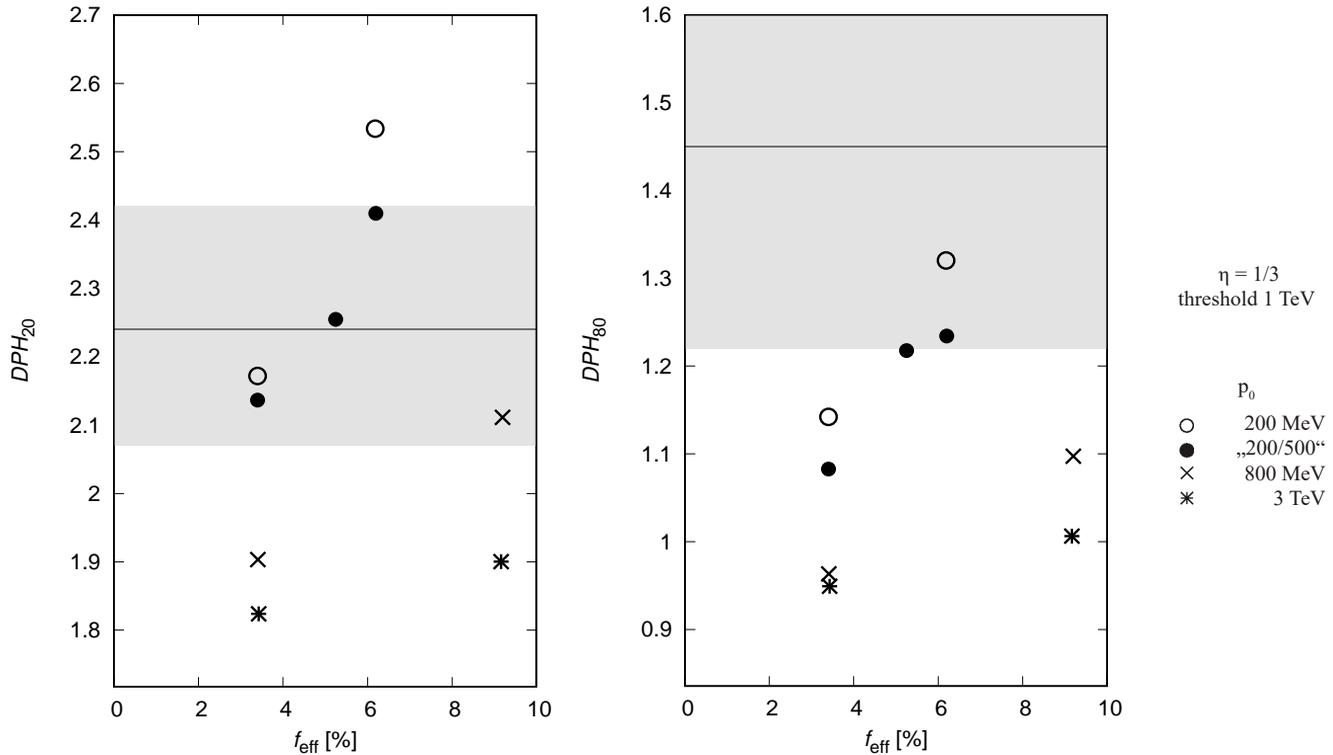
$p_0 = 200$ MeV @ threshold
500 MeV @ 100 TeV

$p_0 = 200$ MeV

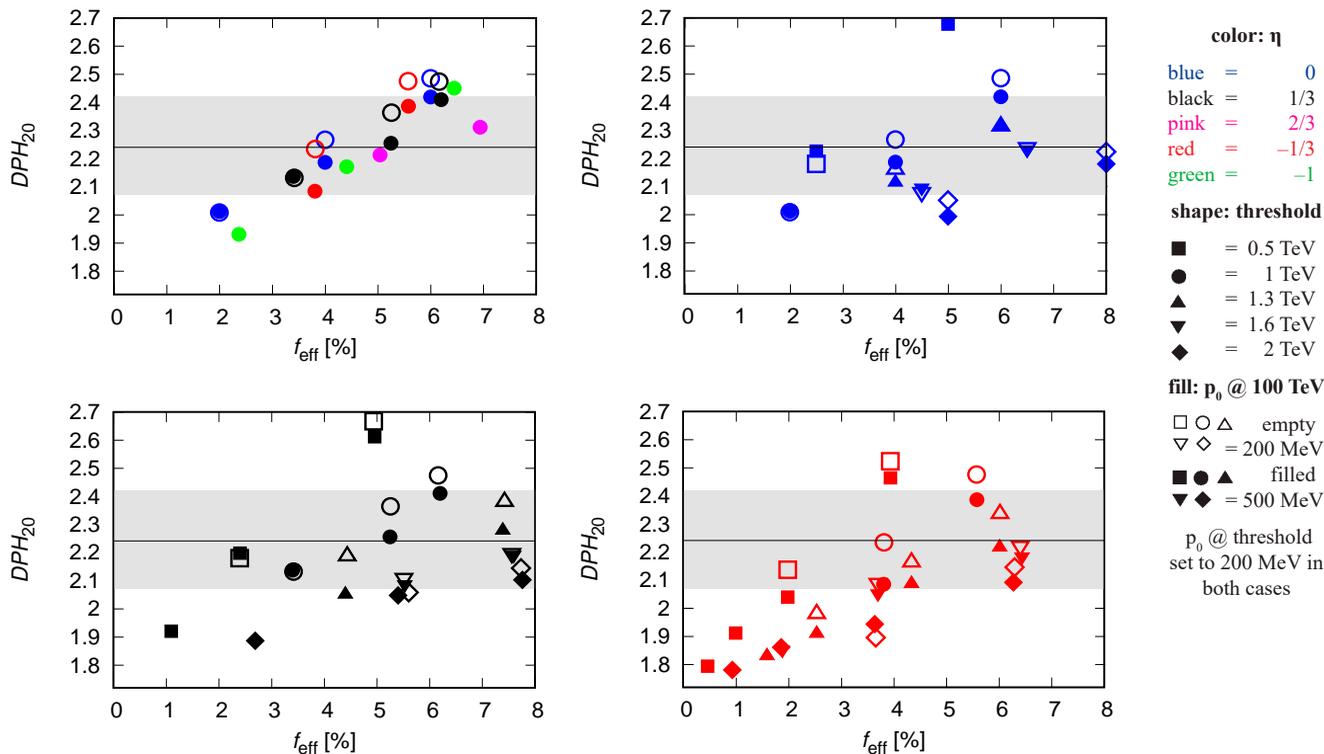
× $p_0 = 800$ MeV
* $p_0 = 3$ TeV

$\eta = 1/3$ and threshold 1 TeV

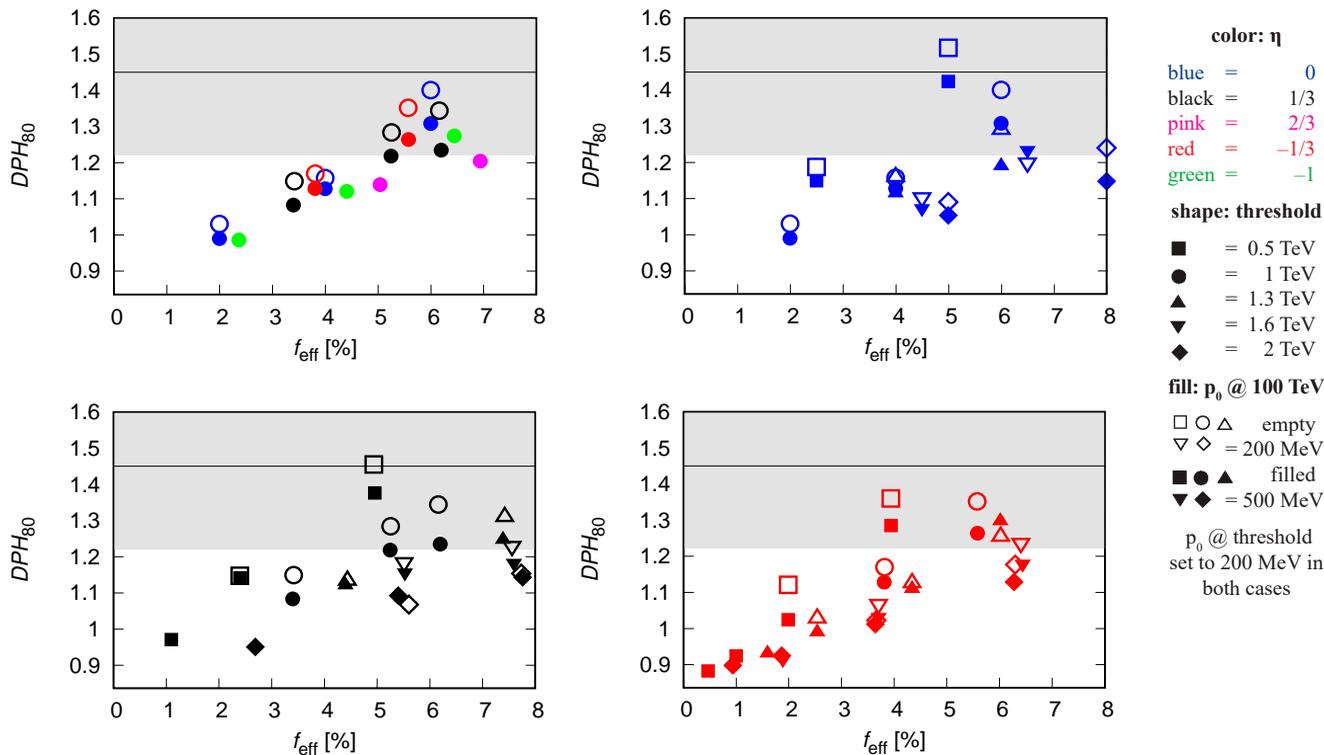
SPAM: momentum distribution



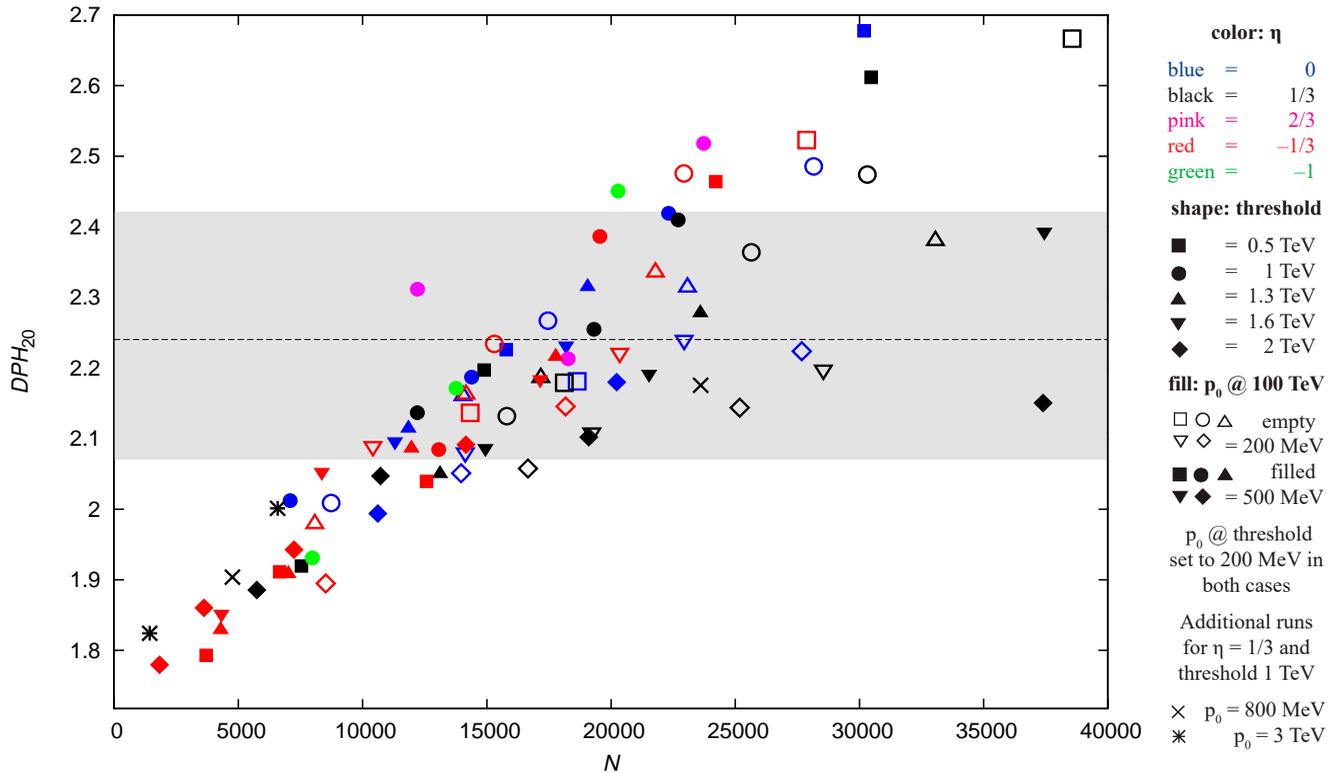
SPAM: DELPHI data at multiplicities >20



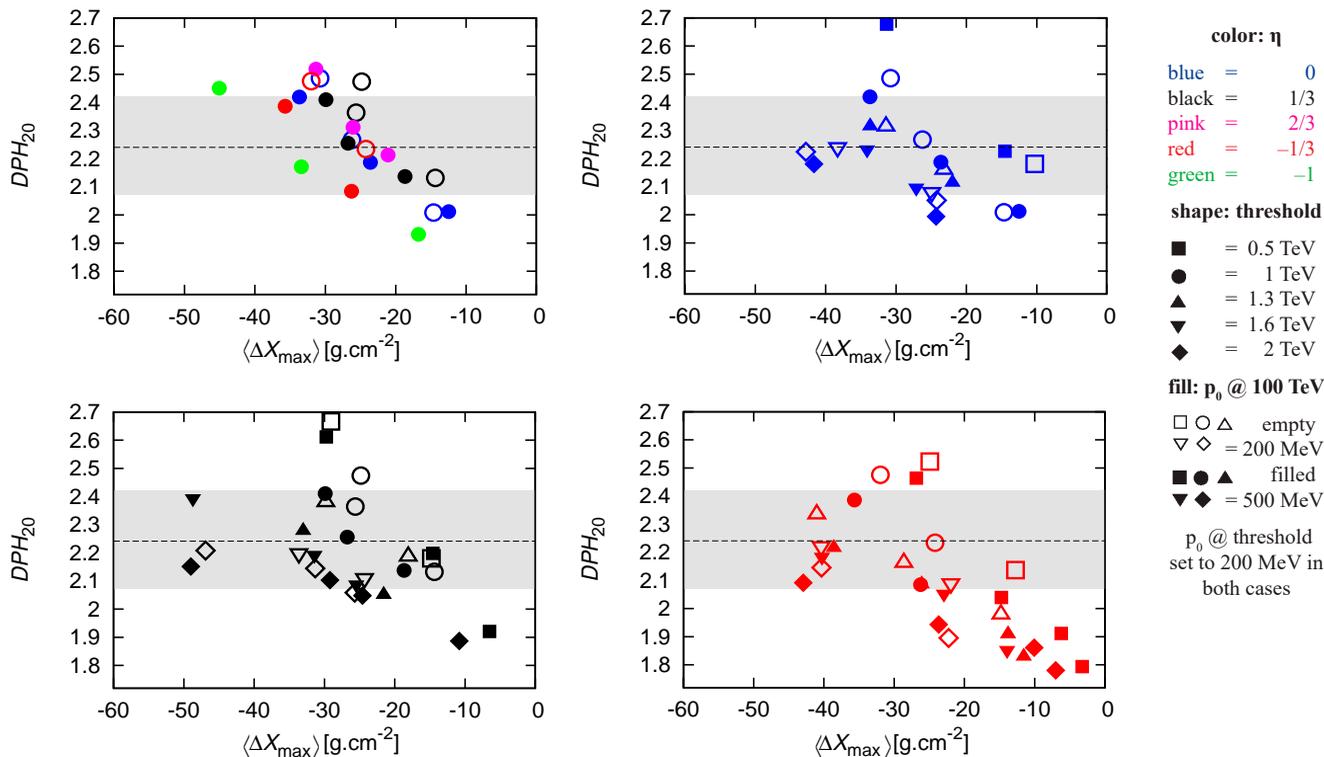
SPAM: DELPHI data at multiplicities >80



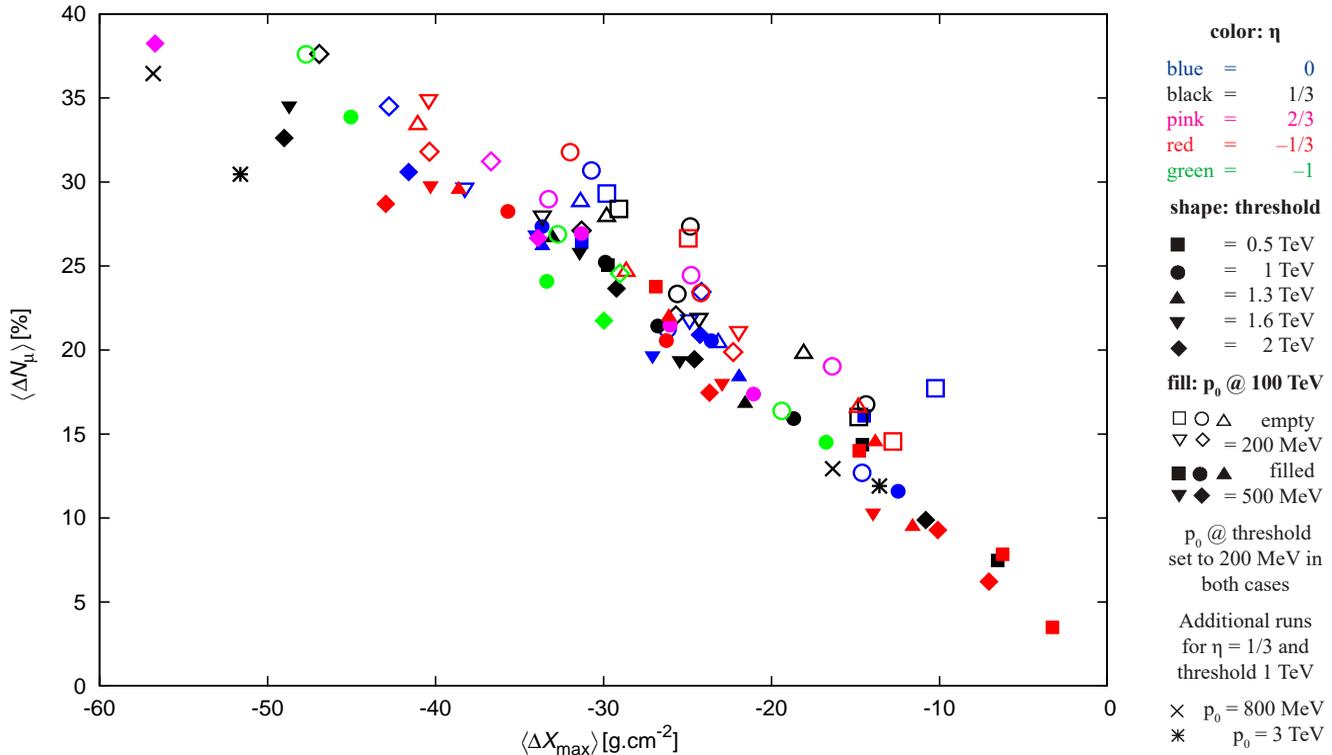
SPAM: total number of added particles



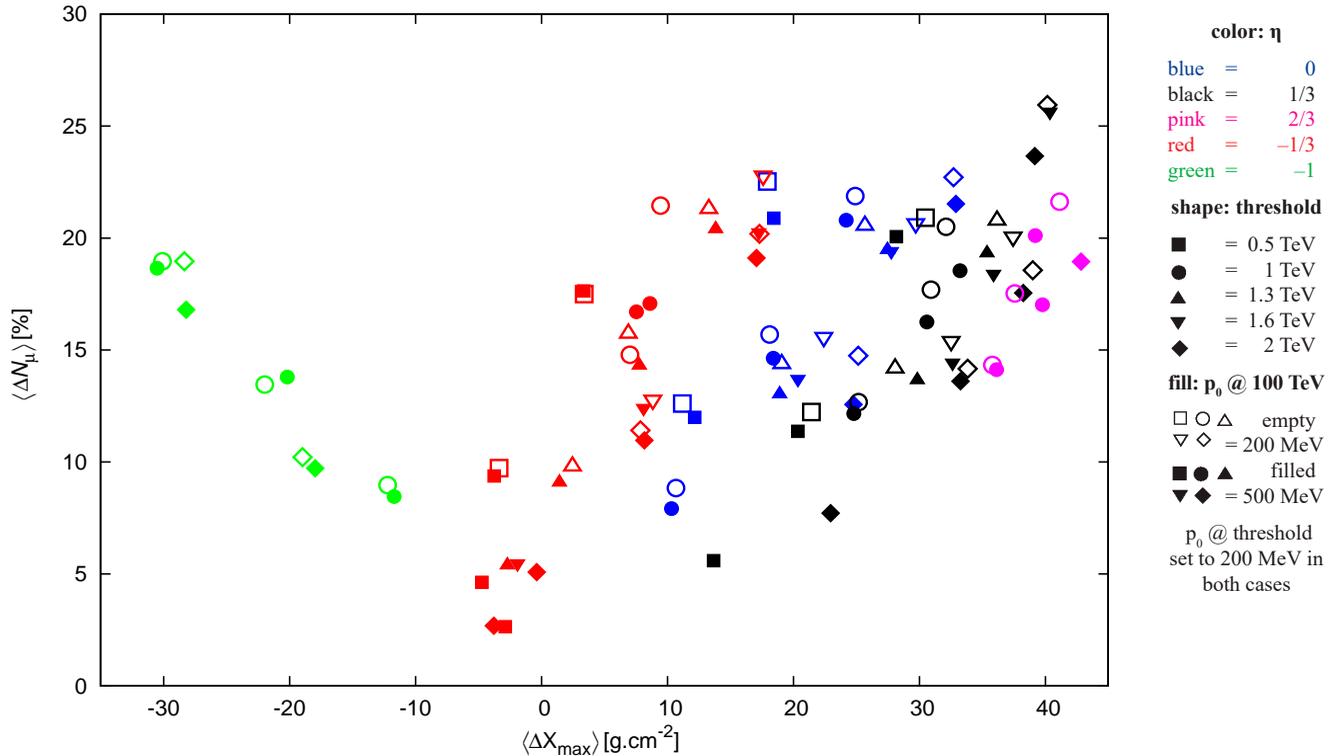
SPAM: DELPHI vs. Auger X_{\max}



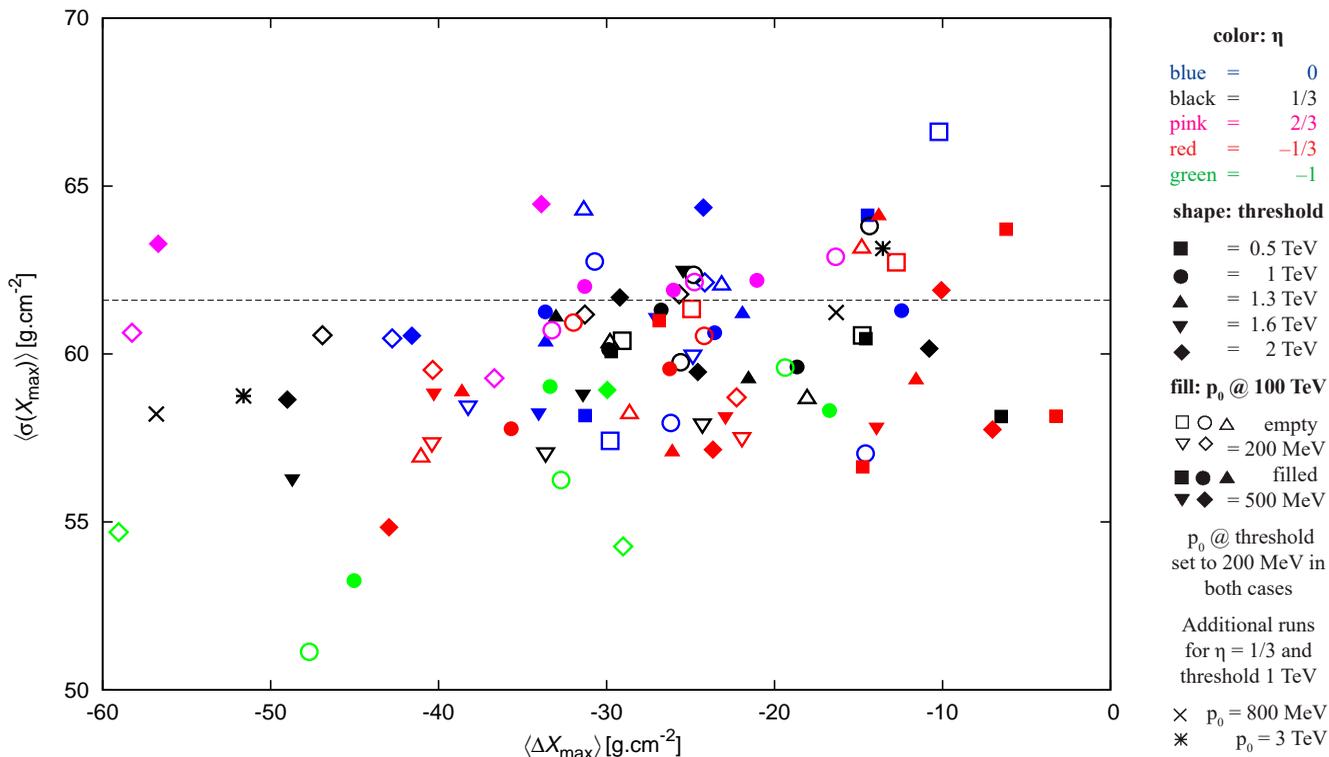
SPAM: Auger X_{\max} vs. number of muons (protons)



SPAM: Auger X_{\max} vs. number of muons (irons)



SPAM: Auger X_{\max} vs. RMS (protons)



SPAM: Auger X_{\max} vs. RMS (irons)

